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# An Experimental Investigation of Radiation Effects in Semiconductors

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## INTRODUCTION

Studies of the microscopic nature of radiation induced defects in germanium and silicon have continued during the period from 1 January to 30 June, 1965. Optical and electrical studies have been primarily used to determine the energy level associated with the defect and the influence of dopant and impurities upon the efficiency of formation of the defect. Since most of these studies are continuing only an outline of the current status and recent progress will be given here.

## CURRENT RESEARCH

Impurity Band Conduction. A copy of a paper entitled "Compensation Dependence of Impurity Conduction in Antimony Doped Germanium" by E.A. Davis and W.D. Compton [redacted] has been submitted for publication. A second paper entitled "Negative Photoconductivity Associated with Impuity Conduction in Germanium" is being prepared for submission. It is felt that these papers provide a basic understanding of the influence of irradiation induced defects upon the impurity conduction process.

Present work involves a study of the thermal stability of radiation induced defects in the highly doped materials. Samples of material having room temperature resistivities of 0.016 and 0.0085 ohm-cm were irradiated with various fluxes of fast neutrons. Hall coefficient data indicate that the samples had donor concentrations of $1.3 \times 10^{17}$ and $1.9 \times 10^{17}/cm^3$ following irradiations. Values of the resistivity at 273°K, 77°K, and

4.2°K and the Hall coefficient at 273°K and 77°K are being measured after each anneal step. The annealing procedure consists of holding the sample at a specified temperature for 45 minutes, measuring the above listed quantities and then annealing for 45 minutes at a temperature 10°K above the previous anneal. The anneals were begun at 373°K. When the fixed temperature data indicates that a significant change has occurred in any of the resistivity or Hall coefficient values, a complete measurement of the temperature dependence of the resistivity between 77°K and 2°K is made. These studies will be useful in determining whether the thermal stability of defects in the highly doped material is consistent with that which has been found for more pure materials.[1/] It is expected that this work will be completed within the next three months.

Recombination Luminescence. Previous progress reports have argued that luminescence should result from electron-hole recombination via deep levels that are introduced by irradiation. The deep levels would be the recombination centers. This luminescence has now been observed in silicon irradiated with $Co^{60}$ gamma rays. The results are shown in the attached figure. The sample was a single crystal of n-type silicon having a room temperature resistivity of about 100 ohm-cm. The luminescence was excited optically using a 500 watt mercury discharge lamp. The sample was held at 77°K . The dotted curve, on the left, is the band-to-band recombination luminescence that has been reported previously. The width of this luminescence peak is determined by the resolution of the monochromator. Following irradiation with $5.4 \times 10^{7}$ roentgens of $Co^{60}$, the band-to-band

luminescence has disappeared and has been replaced by a broad luminescence at longer wavelength. The luminescence is not observed at room temperature. This result is consistent with a similar observation reported by Ivanov and Ychnevich using p-n junctions that had been irradiated with $Co^{60}$.[2] Measurements with the sample at 4.2°K indicates that the luminescence spectrum is a composite of many sharper emission spectra which are displaced in energy. A high resolution grating monochromator has been ordered to enable us to study these resolved spectra. Studies are currently underway on both n and p samples containing various concetrations of oxygen impurity. It will be important to determine whether the two emission peaks at about 1.33 and 1.65 microns are associated with the same defects or with two different defects.

This new technique will be used to study radiation induced defects in a variety of materials that have been subjected to various types of irradiation. The technique may also be very useful in studying the nature of deep traps in germanium and silicon that are introduced by impurities. A preliminary investigation of the luminescence from cobalt activated silicon has been made.

Minority Carrier Lifetimes. The systematic study of the influence of radiation upon the minority carrier lifetime of silicon is continuing. A study of the dependence of the minority carrier lifetime upon the level of injection of carriers has been made on samples before irradiation. Since the pulsed light source has limited intensity, an auxiliary steady state light source was used in these studies. The results may be summarized as

follows. The n-type samples and the p-type float zone samples had only a small dependence of lifetime upon injection level. In contrast, some p-type Czochralski grown samples had such a strong dependence that it was difficult to determine a reliable value of the minority carrier lifetime. Measurements are continuing on samples listed in the previous semi-annual report. Additional samples from some ten different crystals have been measured prior to irradiation and studies of the effects of $Co^{60}$ gamma rays are underway.

## PERSONNAL

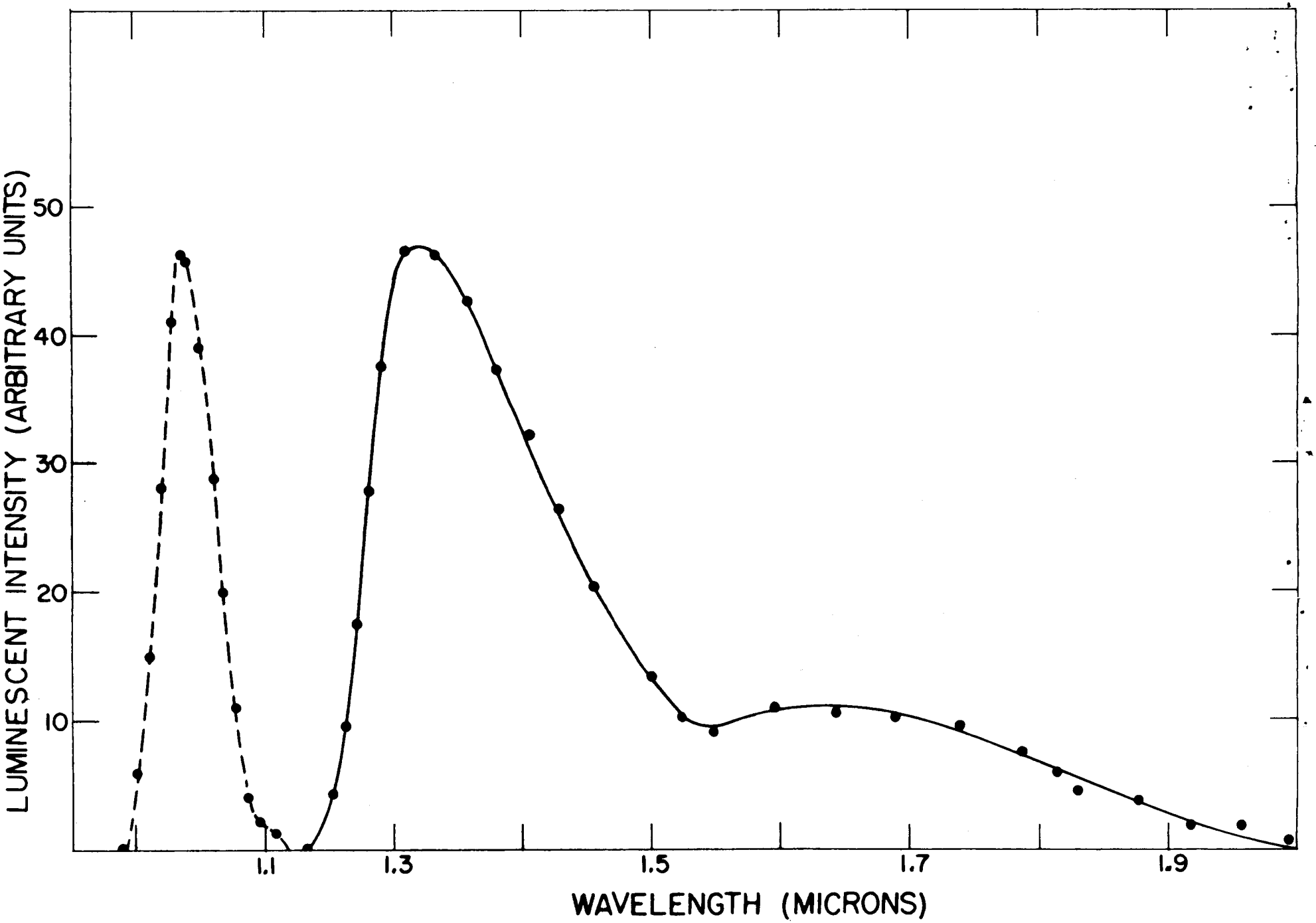
Dr. E.L. Wolf has spent full time on this project. Mr. Robert Spry and Mr. Ralph Hewes are continuing work on the recombination luminescence and the minority carrier lifetimes for their Ph.D. theses. Mr. Steven Depp has been assisting in the measurements of the thermal annealing of the defects.

## REFERENCES

1. J.C. Pigg and J.H. Crawford, Phys. Rev. 135, A1141 (1964).
2. J.L. Ivanov and A.V. Ychnevich, Zh. Techn. Fiz. 6, 3703 (1964).

FIGURE CAPTION

Intensity of luminescence (in arbitrary units) vs wavelength for n-type silicon of about 100 ohm-cm resistivity. Measured at 77°K. Dashed curve, band-to-band recombination luminescence. Solid curve, luminescence following a room temperature irradiation of $5.38 \times 10^7$ roentgen of $Co^{60}$ gamma rays.


LUMINESCENT INTENSITY (ARBITRARY UNITS)
50
40
30
20
10
1.1
1.3
1.5
1.7
1.9
WAVELENGTH (MICRONS)